CHAPTER 7

PRIMARY COMMUNICATION EQUIPMENT

The most important equipments within the purview of the communication officer are receivers, transmitters, and antennas, teletypewriters, and their associated equipment. The most technical knowledge an officer has of his equipment the better prepared he is to solve his operational problems. Obviously one cannot delineate the degree of knowledge which is sufficient to assure excellent performance as a communication officer. Some technical knowledge is necessary. This chapter discusses, to a limited degree, some functionary aspects of communication equipment.

EQUIPMENT DESIGNATING SYSTEMS

The system used by the military services to identify most electronic equipment is the Joint Electronics Type Designation System, more commonly called the "AN" system. The basic equipment nomenclature consists of five indicator letters and a number. The basic designation may be supplemented by letters and numerals that indicate modifications or changes to the equipment.

The system is designed so that its indicators tell, at a glance, important information pertinent to the item: whether the item is a set or only a component, where it is to be used, what kind of equipment it is, and what it is for.

For example, AN/SRT-15 indicates a radio transmitter designed for installation in a surface ship. The designation is broken down as follows (refer to table 7-1): AN tells us that the identification of the equipment is assigned under the AN system. The AN is followed by a slant sign and the three letters SRT. Letter S means the equipment is designed to be carried by a surface ship, R signifies that the item is a radio, and T indicates that the equipment is used for transmitting. The figure 15 is the model number. A modification to the current model would be shown as 15A, a second model would be 15B, and so on.

Although most equipments are identified by the AN system, a considerable number are marked and identified according to the older Navy Model System. This system utilizes three (in isolated cases, two) letters that indicate (1) the application or function of the unit and (2) the approximate order of tis development. For the initial letter(s), the following is the key to the application of the unit:

- D Radio direction finding.
- FS Frequency shift keying.
- L Precision calibrating (such as frequency meters).
- R Radio receiving.
- T Radio transmitting (includes combination transmitting and receiving).

Under the older system, RA is the first radio receiver designated, RB is the second, etc. When the alphabet is exhausted, three-letter designators are assigned as follows: RA. . . RZ, RAA . . . RAZ, RBA . . . RBZ and so on. A numerical suffix (e.g., RB-1) indicates an improved model of a designated unit.

ELECTRON TUBES

The electron tube is considered mainly responsible for the rapid evolution of electronics to its present stage. It is one of the basic components of almost every electronic equipment. Without the discovery and development of the tube, elaborate yet compact equipment such as radio, radar, and sonar would not be possible. A knowledge of electron (vacuum) tubes is basic to understanding the operation of radio receivers and transmitters.

Electron tubes perform many functions. In the field of radio, their greatest usefulness lies in the ability to amplify weak signals. The strength of a signal picked up by the antenna of a radio receiver is in the microvolt region, and signal amplification is required if the human ear is to hear the transmitted intelligence.

The tube is made up of a highly air-evacuated glass or metal shell that enclosed several elements: a cathode (emitter), a plate or anode (collector), and sometimes one or more grids.

Electricity is the flow of free electrons through a conductor. In various ways this flow of electricity can be controlled. Electrons,

Table 7-1. —Equipment Indicator Letters

Installation	Type of Equipment	Purpose
A—Airborne (installed and operated in aircraft) B—Underwater mobile, submarine C—Air transportable (inactivated; do not use) D—Pilotless carrier F—Fixed G—Ground, general ground use (includes two or more ground installations) K—Amphibious M—Ground, mobile (installed as operating unit in a vehicle which has no function other than transporting the equipment) P—Pack or portable (animal or man) S—Water surface craft T—Ground, transportable U—General utility (includes two or more general installation classes, airborne, shipboard, and ground) V—Ground, vehicular (installed in vehicle designed for functions other than carrying electronic equipment, etc., such as tank)	A—Invisible light, heat radiation B—Pigeon C—Carrier D—Radiac E—Nupac F—Photographic G—Telegraph or teletype I—Interphone or public address J—Electromechanical (not otherwise covered) K—Telemetering L—Countermeasures M—Meteorological N—Sound in air P—Radar Q—Sonar or underwater sound R—Radio S—Special types, magnetic, etc., or combinations of types T—Telephone (wire) V—Visual or visible light W—Armament (peculiar to armament, not otherwise covered) X—Facsimile or television	A—Auxiliary assemblies (not complete operating sets) B—Bombing C—Communications (receiving and/or transmitting) D—Direction finder G—Fire control or searchlight directing H—Recording (photographic, meteorological, or sound) L—Searchlight control (inactivated; use "G") M—Maintenance and test assemblies (including tools) N—Navigational aids (including altimeters, beacons, compasses, racons, depth sounding, approach, and landing) P—Reproducing (photographic and/or sound) Q—Special, or combination of purposes R—Receiving, passive detecting S—Detecting and/or range and bearing T—Transmitting W—Control X—Identification and recognition

which are negatively charged particles, always flow toward any area which is positively charged. Here, as in all of nature, the maxim that opposites attract is true.

Certain metals, when heated, emit free electrons. In most cases the electrons fall back into the metal. However, if we change the conditions somewhat, we can cause the electrons to leave permanently.

DIODES

Figure 7-1 shows a simple two-electrode or two-element schematic of a diode (di, the prefix signifying two, combined with the suffix ode from Greek "hodos," meaning way or path, found in such words as cathode, electrode, and anode. The cathode is made of a material, such as tungsten or oxide-coated nickel alloy, that gives off electrons when heated. In the illustration, the cathode is heated by battery A. If the cathode is encased in a container with

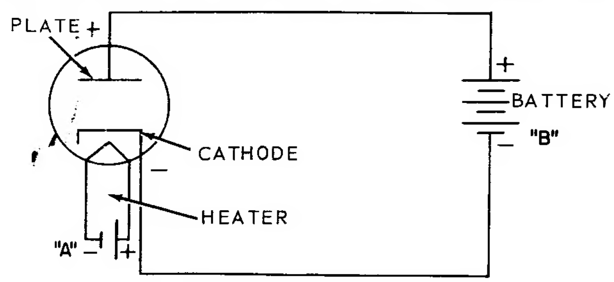

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Figure 7-1. —Diode schematic.

another piece of metal and the air is removed, proper conditions are present to cause the electrons to flow. Evacuation of air from the tube is required to (1) prevent destruction of the cathode and heating element by oxidation or burning, and (2) permit the uninterrupted flow of current from cathode to plate (anode). The lightest gas particle is approximately 1800 times the weight of an electron. Molecules of air would divert electrons upon impact and make the current flow erratic.

To start the flow of electrons, heat is applied to the cathode by the filament. Then voltage is applied to the plate (in our example using battery B), and the cathode is caused to be negatively charged with respect to the plate. The heated cathode emits electrons that move across the open space toward the anode (plate). Because a positive potential exists on the anode with respect to the cathode, the movement of electrons is continuous so long as voltage is applied, causing a flow of current. The higher the plate voltage, the stronger the force, and the more electrons are pulled from the cathode. Eventually a plate voltage value is reached at which all the electrons being emitted are in transit to the plate. The tube has then reached its saturation point, and any further increase in plate voltage can cause no further increase in plate current flowing through the tube.

TRIODES

The triode, or three-element electron tube, is similar in construction to the diode, except that a grid of fine wire is added between the cathode and the plate. The grid usually is in the form of either a spiral helix with the cathode at the center, as in figure 7-2, or a mesh screen.

The plate current in a diode depends on plate voltage and cathode temperature. The number of electrons (i. e., the current) flowing through the tube can be controlled in two ways: by changing the plate voltage and by changing the temperature of the cathode. In a triode, the flow of current to the plate also is controlled by applying voltage directly to the grid.

Electrons leaving the heated cathode (filament) fill the space between cathode and plate, and exert a repelling force on the electrons that follow. This results in a relatively large cloud of electrons, called a space charge, near the cathode. The space charge, in effect, is a

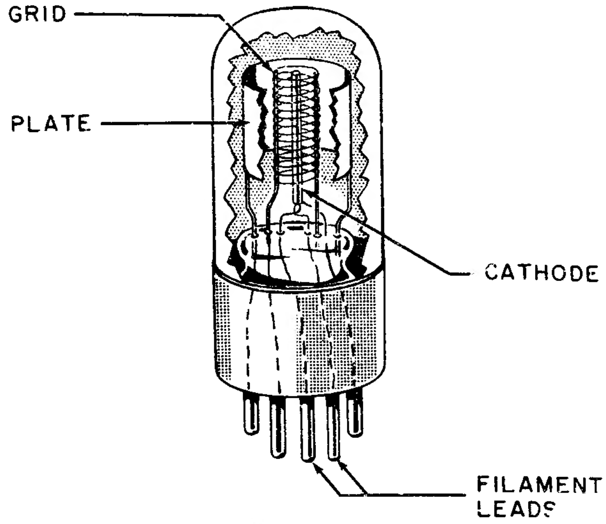

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Figure 7-2. —The third element of a triode is a wire grid.

negatively charged electrode near the filament that limits the amount of current that can flow for a given plate voltage, opposing the attraction of the positive plate.

By placing a metallic grid near or within the negative space charge, it is possible to control the plate current without changing either plate voltage or filament temperature. The open spaces of the grid mesh must be sufficiently large not to block the flow of electrons. On the other hand, the spaces must be small enough to control effectively the flow of plate current when the proper voltage is applied between the grid and cathode.

To control the current by means of the grid, the grid voltage is made less or more negative with respect to the cathode by means of an electrical lead in the base of the tube. When the grid is made more negative than the cathode, it blocks the flow of current because the higher negative charge repels the electrons back toward the filament (cathode). As long as the grid is negative with respect to the cathode, no grid current flows and no power is consumed in the grid circuit. The smallest voltage between grid and cathode that will cut off the flow of plate current, the grid being negative, is called the cutoff bias.

When the grid is made positive with respect to the cathode, the electrons in the space charge are accelerated toward the plate. Consequently, cathode-to-plate potential being the same, more

current can be made to flow than is possible when no grid is present. Because the grid is so close to the space charge, the grid-to-cathode voltage has a much greater effect on current flowing through the tube than does voltage between the plate and cathode.

The addition of the grid gives to the electron tube its most useful function—the ability to amplify an input signal. Because of the grid's boosting action, a small change in the grid input signal is accompanied by a relatively large change in plate output signal. To amplify a received signal, therefore, it is more efficient to apply a small change in voltage directly to the grid rather than to apply a large change in voltage to the plate. The grid signal is said to be amplified in the plate circuit. The grid itself may be considered as an electronic control valve that regulates the flow of electrons through the tube and through the load in the plate circuit.

Amplification of the signal is necessary because the r-f energy arriving at the antenna is a very small portion of the total energy transmitted. The received energy, or signal, is applied electronically between the grid and the filament of a triode. By selecting the proper tube, a change of a few volts or microvolts (plus or minus) in grid voltage can result in a large change of current flow to the plate. In this way a small variation in grid voltage can be multiplied 10, 20, or more times in the output signal. This signal may be fed to another triode for further amplification. For example, a 0.2-volt input signal may be amplified 20 times in tube A, resulting in a plate voltage of 4 volts. If the amplified signal is routed to a second tube capable of amplifying 20 times, the result is a second-stage amplification of 80 volts (20 x 4), or a total amplification of 400 (80/.2).

Figure 7-2 shows the construction features of a typical triode. Electrical connections to the grid and plate are made through the base pins and support wires of the tube. The cathode sleeve is insulated from the filament and is connected by means of a short lead to one of the base pins. The grid is much closer to the cathode than to the plate.

MULTIELEMENT TUBES

Many desirable characteristics may be attained in electronic tubes by the use of more than one grid. Common types include tetrodes and pentodes, which contain four and five electrodes, respectively. Tubes containing as many as eight electrodes are available for certain applications. Other refinements include beam-power tubes, gas-filled tubes, and variable-mu tubes, the technical details of which need not be discussed.

To reduce the number of tubes in radio circuits, the electrodes of two or more tubes frequently are placed within one envelope. Known as multiunit tubes, they generally are identified according to the way the individual types contained in the envelope would be identified if they were made as separate units. A multiunit tube may be identified, therefore, as a duo-diode, a diode-pentode, a diode-triode-pentode, and so on.

OSCILLATORS

In out discussion of frequencies, it was pointed out that a transmitter sends out intelligence on a specific frequency, and that a radio receiver, if it is to capture that intelligence, must be tuned to the same frequency. In the transmitter the basic frequency is generated by some form of oscillator.

Basic to an understanding of an oscillator's function is a knowledge of the principles of resonance. Every substance has a natural frequency at which it vibrates. If a singer raises the pitch of his voice to a certain level, he can shatter glass. The vibrations of the sound wave produced by his vocal cords reach the natural frequency of the glass, and the glass in turn vibrates so much that it breaks. Two objects vibrating at the same frequency are said to be in resonance.

When a transmitted radio wave strikes a receiving antenna, the wave of r-f energy sets up a current (vibration) through the antenna. The current is strongest when the frequency of the receiving antenna is the same as (is resonant with) that of the transmitting antenna. The induced current under this condition meets the least amount of opposition in the circuit. If the two antennas operate on different frequencies, a current also may be induced in the receiving antenna, but it will meet with greater opposition.

If, therefore, the resonant frequency of transmitter A is 150 kc, and that of B is 450 kc, and if the resonant frequency at the receiver happens to be—at the time—150 kc, the receiver offers minimum opposition to frequency A. In effect, the receiver rejects the signal from

transmitter B and accepts the signal from transmitter A.

The primary function of an oscillator is to generate a flow of r-f energy and to maintain that frequency within certain limits. In addition to their use as amplifiers, electron tubes are used as oscillators for the generation of alternating, or oscillatory, voltages. The tube itself, however, is not an oscillator. The oscillations actually take place in the tuned circuit. The electron tube functions mainly as an electronic valve that amplifies and automatically delivers to the grid circuit the proper amount of energy to maintain oscillation and, therefore, resonance.

An important requirement of an oscillator is that it accurately maintain the frequency to which it is adjusted. The ability of an oscillator to maintain a constant frequency under variable operating conditions is referred to as frequency stability. Variations in plate voltage, stability of mechanical parts, loading, and temperature are some of the factors that influence frequency stability. Dynamic instability is the term used to describe sudden frequency changes. Gradual frequency changes are referred to as drift.

Some of the precautions usually taken to ensure frequency stability are: (1) the use of a regulated power supply, (2) reduction of the r-f load to a minimum, (3) provision of a warmup period before setting the oscillator to the desired frequency, and (4) stable mounting of the oscillator components so that changes in circuit constants resulting from mechanical motion are minimized.

Many variations of self-controlled, or self-excited oscillator circuits are in use. In general, these built-in oscillators are placed within the tube between the grid and cathode. Most of these have the disadvantage of a slight frequency drift resulting from temperature and load changes. In order to have a source of r-f energy that is constant and subject to practically no frequency changes, substances called crystals are used in the oscillator. When so used, the crystal determines the oscillating frequency. To change the frequency of a crystal-controlled oscillator, it is necessary only to replace the crystal with one that will vibrate at the desired frequency when electrically energized.

Several crystalline substances such as Rochelle salt, tourmaline, and quartz have the property of vibrating mechanically at a particular frequency when an electromotive force is applied to them. The magnitude of the response obtained from the crystal depends on the type of crystal employed, the way it is cut, and the manner in which the emf is impressed. For several reasons, mainly stability and ruggedness, quartz-crystal oscillators are preferred.

The crystals must be cut and ground to close tolerances. For example, the dimensions for a typical quartz crystal resonant at 1000 kc is approximately 1 x 1 x 0.1125 inch. For use at higher frequencies, some crystal elements are disk shaped or cut in the form of a flat ring. Crystals usually are rated according to the maximum r-f current which they can tolerate without heat fracture.

Electrical contact with the crystal is made by a crystal holder consisting of two metal plates, between which the crystal is placed, and a spring device that places mechanical pressure on the plates. Contact also may be made by soldering connecting wires to a metallic film deposited on the surface of the crystal.

TRANSMITTERS

Radio transmitters used by the U. S. Navy range from the largest in the world, which is the million-watt VLF installation at Cutler, Maine, to the 0.027-watt handie-talkie. Most ships are equipped with transmitters rated at between 100 and 500 watts for use in the LF band through the UHF band. There are no shipboard VLF transmitters because of the prohibitive size required to generate the necessary operating power.

CLASSIFICATION OF EMISSIONS

Radio wave transmissions originally were classified, by international agreement, only according to the type of transmission (modulation). The classification for CW telegraphy was simple A1, telephony was A3, FAX A4, and the like. This system of classification proved inadequate because of the introduction into the field of communications of such systems as pulse-time modulation, frequency-shift keying, and multiplexing.

In 1947, the International Telecommunication Convention (ITC) prescribed designators, revised in 1959, that provide more detailed descriptions of emissions. Emissions now are designated according to their classification and necessary bandwidth; they are classified

according to their characteristics. An emission designator normally has four parts, consisting of—

	Symbol
1. Bandwidth occupied (in kc).	
2. Type of modulation of main carrier:	
a. Amplitude	A
b. Frequency and phase	F
c. Pulse (for radar transmission)	P
3. Type of transmission:	
a. Absence of any modulation intended to carry information	0
b. Telegraphy without the use of modulating audiofrequency	1
c. Telegraphy by the on-off keying of a modulating audiofrequency or audiofrequencies, or by the on-off keying of modulated emissions	2
d. Telephone	3
e. Facsimile	4
f. Television	5
g. Four-frequency duplex telegraphy	6
h. Multichannel voice-frequency telegraphy	7
i. Cases not covered by the above	9
4. Supplementary characteristics:	
a. Double sideband	None
b. Single sideband:	
(1) Reduced carrier	A
(2) Full carrier	H
(3) Suppressed carrier	J
c. Two independent sidebands	B
d. Vestigial sideband	C
e. Pulse:	
(1) Amplitude-modulated	D
(2) Width-(or duration) modulated	E
(3) Phase-(or position modulated	F
(4) Code-modulated	G

Under the foregoing system, the designator 3A3A indicates—

3—bandwidth 3 kc (part 1);
A—amplitude-modulated (part 2);
3—telephony (part 3);
A—reduced carrier (part 4).

The following types of emissions are representative of some of those now applicable to naval communications:

3A3A	AM SSB telephony.
6A3	AM telephony.
36F3	FM telephony.
0.1A1	CW telegraphy, 25 wpm.
1.5A2	Tone-modulated RATT, 60 wpm.
1.08F1	Single-channel RATT, 60 wpm.
4F4	Facsimile.

HARMONICS

It is difficult to design and build a stable oscillator for use at higher frequencies; and, if a crystal is employed to control an HF oscillator, it must be ground so thin that it may fracture while vibrating. To overcome the problem, HF transmitters utilize oscillators that operate at comparatively low frequencies. The oscillator frequency then is raised to the required output frequency of being passed through one or more frequency multipliers, which are special power amplifiers. Multipliers that double the freqeuncy are doublers, those which multiply by three are triplers, and so on.

Harmonics are the exact multiples of the basic, or fundamental, frequency generated by the oscillator. Even harmonics are even multiplies times the fundamental; odd harmonics are odd multiplies of the fundamental. If an oscillator has a basic frequency of 2500 kc, harmonically related frequencies are—

2d harmonic . . . . . . 5000 kc.
3d harmonic . . . . . . 7500 kc.
4th harmonic . . . . . . 10,000 kc.

The series ascends indefinitely until the signal is too weak to be detected. The r-f energy remaining in frequencies above the third harmonic usually is insignificant.

The main difference between many LF and HF transmitters is in the number of frequency-multiplying stages employed.

TRANSMISSION OF INFORMATION

The r-f energy radiated by a transmitting antenna conveys no intelligence in itself. It

simply "carries" intelligence superimposed upon it. The power wave is referred to as the carrier wave, or carrier.

Continuous Wave (CW) Transmission

In CW radiotelegraph transmissions, information is transmitted by alternately starting and stopping the flow of power from transmitter to antenna by means of a telegraph key. Messages are sent by means of short and long pulses that correspond to letters and numerals of the Morse code. The carrier is merely turned on and off; it is not changed in either frequency or amplitude.

For other than CW transmissions, the process of superimposing useful information on the carrier is called modulation.

Amplitude Modulation

Let us consider the problem of sending audible signals so that one may speak directly into a microphone at the transmitting station and be heard and understood at the receiving station.

We have stated that a radiofrequency is above 15 kilocycles and an audiofrequency is below that frequency. Actually, voice frequencies run considerably below that figure. Against a similar time scale we can illustrate the comparative sizes of radiofrequency waves and audiofrequency waves as in figure 7-3. Many cycles of radiofrequency waves are completed within 1 cycle of audiofrequency. For instance, 1000 cycles per second is audible, and within the time of 1 cycle (1/1000 second), a 50-kc radiofrequency would complete 50 cycles.

To transmit an audible signal, the carrier waveform may be modulated in accordance with the variations in the audio tones to be transmitted. The source of the modulating signal is the output voltage of the microphone. A microphone is essentially an energy converter that changes acoustical energy into corresponding electrical energy. Speech, music, or any other form of intelligence is first converted into alternating voltages. The voltages, in turn, are electronically superimposed on the carrier before its transmission in order to modulate the amplitude of the carrier. This method of impressing modulating frequencies on the carrier waves is called amplitude modulation (a-m).

STAGES WITHIN AN A-M TRANSMITTER.—An audio signal entering the microphone is amplified by one or more audiofrequency (a-f) speech amplifiers and by the a-f modulator, as seen in figure 7-4. The a-f voltage supplied by the microphone usually is less than 1 volt. The addition of such a low a-c voltage to the comparatively high d-c potentials in the tube results in a very small variation in the power output. It is necessary, therefore, to amplify the audiofrequencies from the microphone to a level high enough to cause considerable variation in the power output of the transmitter.

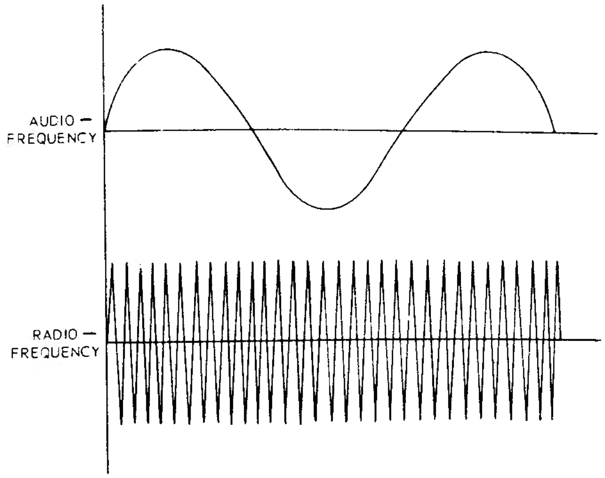

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Figure 7-3.—Comparison of audiofrequency and radiofrequency waves.

The oscillator produces the r-f carrier wave which is amplified by the r-f buffer amplifiers (see fig. 7-4). Buffer amplifiers, in most cases located between the oscillator and the r-f amplifiers, isolate the oscillator from the load to improve frequency stability. The outputs of the a-f modulator and the r-f buffer amplifiers are mixed in the final r-f amplifier to produce the modulated carrier wave. Frequency multipliers raise the oscillator output frequency of the transmitter to the desired carrier frequency.

The stage that the modulator feeds is known as the modulated r-f amplifier. If the modulation voltage is sent into the power amplifier stage such a transmitter is said to be using high-level modulation; if the modulation is accomplished in an earlier stage, the transmitter is said to use low-level modulation. High-level modulation is more efficient; low-level modulation requires less power. Navy transmitters

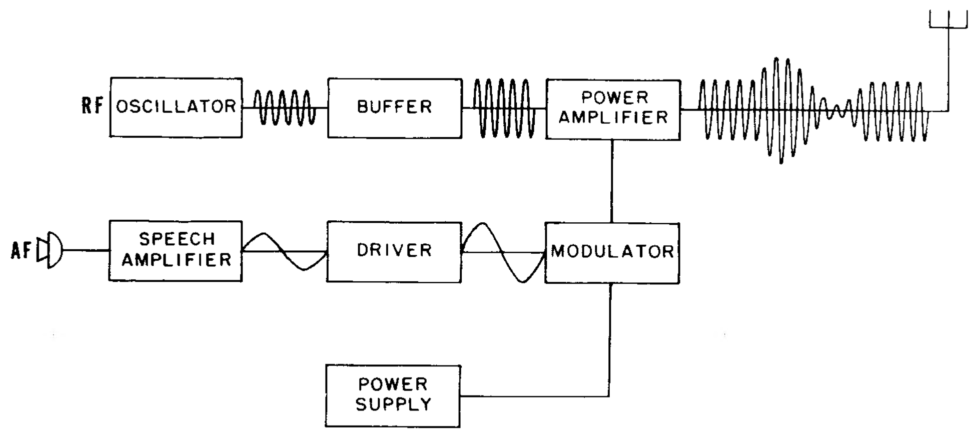

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Figure 7-4. —AM radiotelephone transmitter.

employ high-level modulation except when weight is an important consideration, as it is in aircraft and portable equipment.

Figure 7-5 shows an amplitude modulated radiofrequency. The top envelope of the r-f conforms to the shape of the audio signal below it. The lower part of the a-m signal is just the opposite of the upper part. The mixing of the radiofrequency and audiofrequency is accomplished in a transmitter by means of a modulator circuit. The modulated frequency then goes to the antenna, which radiates the electromagnetic wave into space.

As an aid to understanding the modulator circuit, figure 7-6 shows a simplified schematic of a modulator of the grid-bias type.

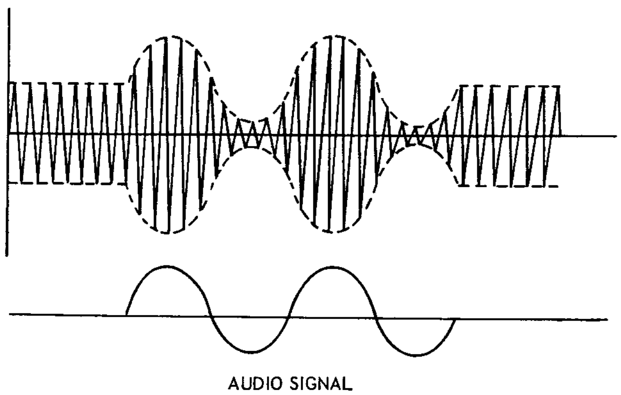

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Figure 7-5. —Amplitude modulated radiofrequency.

The modulator varies the grid voltage of the triode in accordance with the audiofrequency. The current passing through the tube increases as the audio wave becomes more positive and decreases as it becomes more negative. At the same time, the radiofrequency is being coupled to the grid by the capacitor shown to the left of the grid in the drawing. Instead of the r-f signal being amplified without change, as we saw earlier in this chapter, the varying of the grid charge by the audio signal varies the current passage, and the output signal on the plate is the modulated r-f signal shown in figure 7-6. The audio signal is coupled to the grid by a transformer, and the output signal is coupled to the antenna in the same way. The two batteries maintain the charge on the grid slightly less than on the cathode, and the cathode charge is much less than that on the plate.

In practice, the batteries are replaced by electronic power supplies, and many additional components are needed to control the circuit.

ANALYSIS OF AMPLITUDE MODULATION. —An inherent disadvantage of the a-m method of transmitting is frequency extravagance. When an audiofrequency is employed to modulate a radiofrequency, the width of the r-f spectrum needed for communicating is twice the highest modulating frequency because of the introduction of sidebands.

When an r-f carrier is modulated by an audio note, two additional (side) frequencies are produced: an upper side frequency and a lower side frequency. The upper frequency equals the sum of the carrier frequency and the

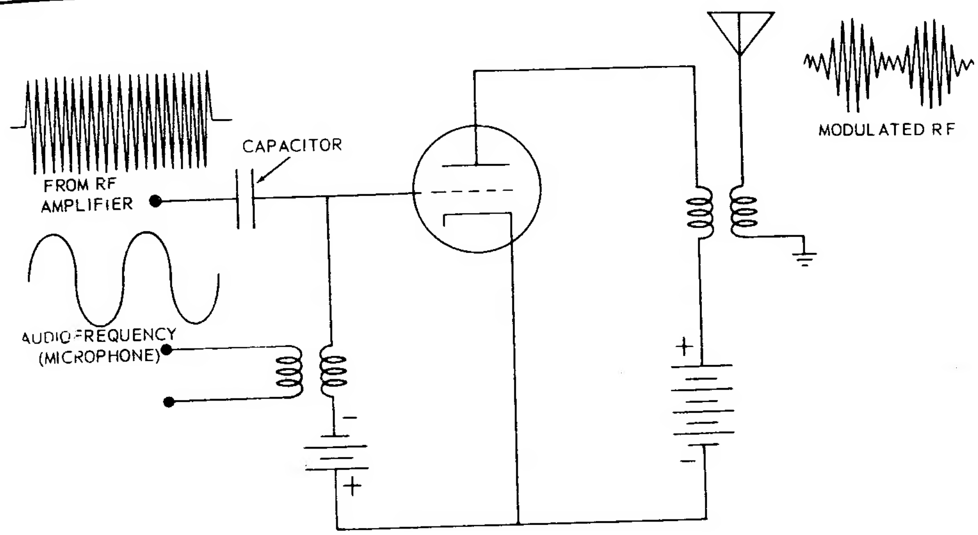

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Figure 7-6. —Grid-bias modulator.

frequency of the audio note, while the lower frequency equals the difference between the two. The side frequencies, then, occupy a band of frequencies lying between the carrier and both the upper and lower limits of the modulating frequencies, as in figure 7-7. When a modulating signal is made up of complex tones, such as those caused by speech, each individual frequency component of the signal produces its own upper and lower side frequencies.

The bands of frequencies containing the side frequencies are referred to as sidebands, and the space that a carrier and its associated sidebands occupy in the r-f spectrum is the bandwidth. The bandwidth, therefore, is equal to twice the highest modulating frequency.

In figure 7-7, a 5000-kc carrier is modulated by a band of frequencies ranging from 200 to 5000 cycles (0.2 to 5 kc). The upper sideband extends from 5000.2 to 5005 kc; the lower

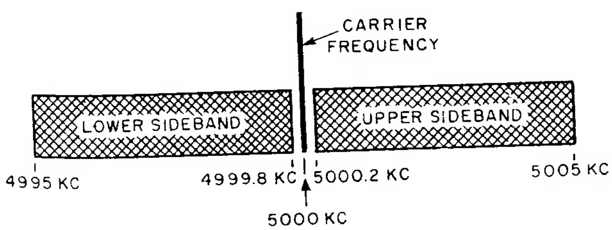

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Figure 7-7. —Sidebands produced by amplitude modulation.

sideband extends from 4999.8 to 4995 kc. The bandwidth, 10 kc (4995 to 5005), is twice the value of the highest modulating frequency, which is 5 kc.

Modulated Continuous Wave

Another mode of operation provided by many medium— and high-frequency transmitters and nearly all VHF-UHF equipment is known as modulated continuous wave (MCW) telegraph transmission. These transmitters are designed for both CW radiotelegraph and a-m radiotelephone transmission.

An MCW transmitter has an audiofrequency oscillator generating a note of constant frequency that is used to modulate the r-f carrier. The received sound is at the frequency of the audio oscillator. Modulated CW telegraphy has a slightly greater distance range than voice modulation for the same transmitter. The range of MCW, however, is always less than that of CW transmission of the same transmitter and, for this reason, is seldom used.

Modern shipboard medium- and high-frequency transmitters also provide other modes of operation, such as frequency-shift keying for radioteletypewriter transmission. This subject is treated fully in a later chapter.

Frequency Modulation and Phase Modulation

In addition to its amplitude, a carrier wave has two other characteristics that can be varied to produce an intelligence-carrying signal. These are its frequency and its phase. The process of varying the frequency in accordance with the audiofrequencies of voice or music is called frequency modulation (FM), and the process of varying the phase is phase modulation. The two types of modulation are closely related. When either is employed, the other is indirectly affected.

The primary advantages of FM are improved fidelity and increased freedom from static. Because of these qualities, it is of considerable use in commercial broadcasting, but its shortcomings—frequency extravagance, short range on available frequencies, and others—severely limit its naval communication applications. The Navy has, however, found FM satisfactory for other purposes, among them altimeters and some radars.

Single Sideband Transmission

Conventional amplitude modulation is often referred to as double sideband (DSB). A mode of radio wave emission that is increasingly important to the fleet is known as single sideband (SSB). The SSB has been employed extensively in shore communication systems for many years. Technological developments that have reduced the physical sizes of equipments now make it feasible to utilize SSB for fleet communications as well.

In DSB transmissions, modulation of the carrier produces a complex signal consisting of three individual waves: the orginal carrier and two identical sidebands. This is an uneconomical means of transmission, because both sidebands carry the same intelligence. The theory of the SSB is that by suppressing the carrier and one of the sidebands as in figure 7-8, the same intelligence can be sent at a saving in power and frequency bandwidth.

In SSB, the carrier is eliminated at the transmitter. This usually is the most difficult or troublesome aspect in understanding SSB. In single sideband suppressed carrier transmissions, there is no carrier present under modulation conditions. As a result, all the r-f energy appearing at the transmitter output is concentrated in "talk power." In addition,

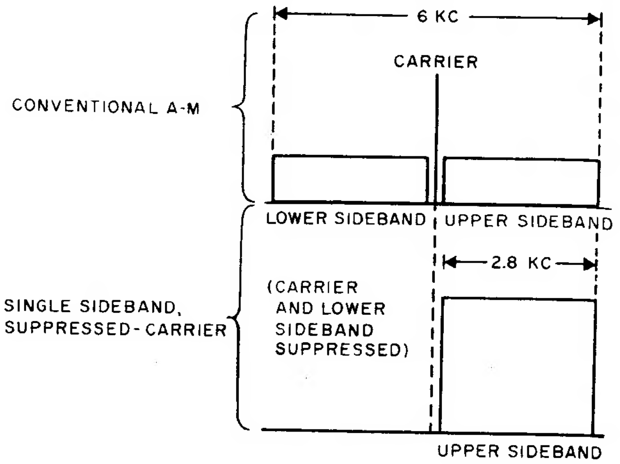

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Figure 7-8. —Comparison of bandwidths of conventional AM and SSB voice channels.

one of the two sidebands is filtered out before it reaches the power amplifier stage of the transmitter. The desired intelligence is then transmitted only on the remaining sideband.

ADVANTAGES OF SSB. —It has been pointed out that in DSB there are two sidebands which are heterodyned (mixed) with the transmitted carrier. If these sidebands are not received in phase (usually because of multipath skywave propagation conditions), the signal heard is fuzzy, distorted, and possibly quite loud. One sideband may experience a slight phase shift due to the multipath transmission, thereby nearly canceling the other sideband. This produces distortion and lose of intelligibility. Fading or slight phase shift of the carrier can produce similar results. However, with the suppressed-carrier type of SSB, these problems are minimized. There are several other important advantages.

In a conventional DSB system, approximately one-half of the transmitter's power goes into carrier, assuming 100 percent modulation, and the remaining one-half is divided equally between the two sidebands. However, with the suppressed-carrier SSB system, virtually all of this power goes into a single sideband which carries the useful voice intelligence.

Because one sideband is eliminated, the bandwidth required for SSB voice circuits is approximately one-half of that needed for DSB. The number of available voice channels utilizing the same frequency in the radio spectrum therefore is doubled. With the scarcity of

frequencies available for new assignments in the spectrum, particularly in the 2- to 30-mc range, this is an important advantage in fleet communications.

In normal voice DSB communication systems, the carrier of the transmitting station remains on the air until the transmitter is turned off. If an additional station transmits while the carrier of the other station is on, squeals and howls result. These are caused by the heterodyning of two or more signals transmitting at the same time. In SSB, as soon as the individual stops speaking into the microphone, talk power in the single sideband leaves the air. Even though two stations may transmit at the same time, it may be possible for a receiving station to read through the interfering station the same way we are able to listen to more than one conversation at the same time.

The range of standard shipboard voice circuits is relatively limited because transmitters do not have the power for voice modulation that they have for CW telegraphy. Because the effective power of the SSB transmissions are concentrated in one sideband, SSB offers the best method of increasing the range of reliable voice communications.

RADIATION HAZARDS

Biological hazards, such as blindness, sterility, or internal burns are possible results of high-energy radiation fields. This radiation also can be hazardous to EED (electroexplosive device) ordnance and during aviation refueling operations. In the case of ordnance, radiation may cause accidental firing or dudding of the electrically initiated devices.

Reports of ignition of gasoline vapors by r-f induced arcs during aircraft refuelings fortunately are rare. In recent years, however, there has been a significant increase in radiated energy from improved high-power communication and radar equipments. This increase, in turn, raises the potential hazard of r-f induced ignition of volatile fuel-air mixtures. Minimum safe handling distances for fueling operations have been promulgated to the fleet, and this problem will not be discussed here.

Biological Radiation Hazards (RADHAZ)

Until recently the power generated by electronic equipment was low enough that it was not considered a serious biological hazard. The development of r-f transmitting systems with high-power transmitting tubes and high-gain antennas has increased the possibility of biological injury to personnel.

When a man goes aloft to work on an antenna, a basic rule of safety demands that all radio transmitters be secured and that all transmitting antennas be disconnected and grounded. If the proper precautions are carried out, no RADHAZ exists. This discussion is intended mainly to acquaint the communicator with the personnel hazard that exists for men working in the vicinity of equipments radiating at high frequencies.

When considering the biological effects produced by r-f radiation, the wavelength (frequency) of the energy and its relationship to the physical dimensions of the object exposed to radiation become important factors. For any significant affect to occur, the physical size of the exposed object must be the equivalent of at least a tenth of a wavelength at the frequency of radiation. Neglecting other physical measurements of the body, if a man is considered to be a vertical receiving antenna, his electrical length (height) depends entirely upon the radiated frequency. As you know, the higher the frequency of radiation the shorter the wavelength. As the frequency increases, therefore, the wavelength decreases, and the man's height represents an increasingly greater number of electrical wavelengths. Thus the likelihood of biological effects increases with an increase in radiation frequency, particularly when the frequency is in the microwave region.

When electromagnetic energy is absorbed in tissues of the body, it produces heat in the tissues in much the same manner as does infrared radiation or direct sunlight. If an organism cannot dissipate this heat energy as fast as it is produced, the internal temperature of the body will rise. This may result in damage to the tissue and, if the rise is sufficiently high, in destruction of the organism. Temperature regulation in the human body is accomplished mainly through the action of sweat glands (cooling through evaporation) and by heat exchange resulting from peripheral circulation of the blood. Because the body has a limited ability to lose heat through sweating and blood circulation, it can tolerate only a moderate increase above normal body temperature.

Certain organs of the body—such as the eyes, the gall bladder, and the urinary bladder—are

more susceptible than others to the effects of r-f radiation. The eyes, in particular, are very susceptible to thermal damage because they have an inefficient vascular system to circulate blood and exchange heat to the surrounding tissues. Unlike other cells of the body, the transparent lens cells of the eyes cannot be replaced by regrowth. When the cells making up the lens become damaged or die, a cataract may be formed.

Although every effort must be made to protect personnel from exposure to r-f radiation, it is not practicable for the commanding officer to impose blanket restrictions on the use of transmitting antennas. Such a policy would needlessly restrict maintenance and checkout procedures, and might well endanger the ship at a critical time.

The following precautions, as a minimum, should be taken to keep men clear of hazardous intensity levels:

1. Permit no visual inspection of any opening, such as a waveguide, that is emitting r-f energy unless the equipment is definitely secured for the purpose of such an inspection.
2. Operating and maintenance personnel must observe all r-f hazard signs posted in the operating area to ensure that the equipment is operating in such a manner that nearby personnel are not subjected to hazardous levels of radiation.
3. Ensure that all personnel are aware of and observe r-f warning signs in a specific area.
4. When the possibility of accidental exposure exists while the antenna is radiating, require technical personnel to have a man stationed topside, within view of the antenna (but well out of the beam), and in communication with the operator.
5. Ensure that radiation hazard warning signs are available and used, not only where required to be permanently posted, but also for temporarily restricting access to certain parts of the ship while radiating.

Hazards of Electromagnetic Radiation to Ordnance (HERO)

Electrically initiated explosive devices are utilized to initiate booster rocket igniters and warhead detonators, for stage separation in multistage rockets, for high-speed operation of switches and valves, and for many other purposes. Some weapons contain more than 75 EEDs. At the same time, the power of both radar and communication transmitting equipments is being constantly increased.

These trends produce an apparently incompatible situation. Transmitters and their antennas have only one purpose—to radiate electromagnetic energy. On the other hand, the initiating elements of certain ordnance items need only to be supplied with the proper amount of electrical energy for an explosion to take place.

Radiofrequency energy can enter a weapon in one of two ways: as a wave radiated through a hole or crack in the weapon skin, or by conduction through firing leads or other wires that penetrate the weapon enclosure. The degree of hazard to specific devices under all operational conditions is difficult to establish. The precise probabilities of EED actuation depend upon variables of frequency, field strength, geometric orientation, r-f environment, and metallic or personnel contacts with ordnance and aircraft.

The most likely effects of premature actuation are dudding, reduction of realibility, or propellant ignition. In the very worst environments there is a low, but finite, probability of warhead detonation. The most susceptible periods are during assembly, disassembly, loading, unloading, or testing in an r-f field.

To meet the growing need for new shipboard procedures to reduce the hazard to ordnance equipment for r-f radiation, the Bureau of Naval Weapons has sponsored tests which, coordinated with studies by other agencies, has enabled the formation of new guidelines and restrictions for handling electrically initiated ordnance equipment. These guidelines have been published to the fleet by a BUWEPS instruction in the 5101 series, Radio Frequency Hazards Manual. In compliance with that instruction, commanding officers are to establish a procedure whereby radiation from radio and radar antennas is positively controlled and coordinated between personnel handling ordnance and personnel operating the transmitters to ensure the observances of the prescribed operating restrictions.

UHF/HF RELAY. —Measures are being taken to eliminate HERO and RADHAZ to a degree where r-f silence will be unnecessary. Meanwhile, restrictions are placed on the use of HF transmitters under certain conditions involving HERO/RADHAZ effects.

As a partial solution to the restrictions, a UHF/HF relay system has been established whereby a ship having a HERO problem that normally requires emission controls can utilize a UHF transmitter to automatically key long-range HF transmitters in nearby ships. (UHF communication transmissions are permissible under these circumstances because the UHF antennas usually are located high in the ship, away from the HERO danger area.)

The relay system, which may be employed for either voice or teletype transmissions, permits the utilization of one or two long-range HF circuits during HERO conditions. Destroyers, cruisers, and carriers have all equipments required for this system in their normal allowance except for a voice-actuated keyer used for voice communications. This unit has been distributed only to destroyers and cruisers.

Radiation is permitted at frequencies below 540 kc during HERO EMCON. Below 1 mc the radiation resistance of incidental antennas that may be attached to weapons (e.g., aircraft) become vanishingly small, and antenna efficiency drops more rapidly than the capture area increases.

RECEIVERS

Because the signal that is picked up by a receiving antenna is in the range of a few millionths of a volt, the signal must be amplified considerably if it is to be of any value. In addition, the audiofrequency signal, if voice is being received, must be removed from the r-f signal. The purpose of a receiver is to reproduce, usually in the form of sound, the intelligence contained in an intercepted radio wave.

To change the received r-f energy into a form of energy that can be recognized, radio receivers perform the following functions:

SIGNAL INTERCEPTION: Although measured in microvolts, the signal voltage extracted by the receiving antenna is sufficient for subsequent amplification if the noise energy intercepted by the antenna or within the amplifying system is substantially less than the intercepted signal.

SIGNAL SELECTION: The receiver must differentiate between a desired signal frequency and other frequencies intercepted by the antenna. Selection is made by tuned circuits that pass only their resonant frequency (frequency to which the receiver is tuned).

R-F AMPLIFICATION: One or more r-f amplifiers increase the intercepted signal to the level required for recovery of the transmitted intelligence.

DETECTION (DEMODULATION): A detector, or demodulator, circuit separates the modulation signal from the r-f carrier of a received a-m signal. In CW reception, a beat-frequency oscillator is utilized in the receiver circuit. The bfo provides an r-f signal that beats or heterodynes against the frequency injected into the detector. This results in an audiofrequency that can be heard in the headset.

A-F AMPLIFICATION: The signal frequency in the output of the detector usually is very weak. One or more stages of a-f amplification are required to strengthen the audio output of the detector to a level sufficient to operate the headset or loudspeaker.

SOUND REPRODUCTION: The amplified a-f signal is applied to the headset or loudspeaker which translates the electrical a-f variations into corresponding sound waves. For a-m, the sound output of the speaker is a close replica of the original audio sounds at the transmitter. For CW, the sound is a tone the frequency of which depends upon the frequency of the local oscillator (bfo). This tone is heard whenever the key is depressed at the transmitter, and, consequently, it reproduces the interruptions of the r-f carrier in accordance with the Morse code.

FIELD STRENGTH

The amount of voltage induced in an antenna depends upon the length of the antenna and the strength of the carrier wave. The carrier wave, strongest when it leaves the transmitting antenna, it attenuated as it travels until its energy level, called field strength, is too weak to be received.

SENSITIVITY

The sensitivity of a receiver is a measure of how well it can amplify weak signals.

In an area of strong local interference, a receiver needs a strong signal to provide good reception. If local interference has a field strength of, say, 100 microvolts per meter, a signal strength of from 500 to 100 microvolts per meter is required to read through the noise. The same receiver, free from local interference, may give good reception on a

signal strength of 100 microvolts per meter. It is hard to state the exact minimum field strength needed to operate a receiver satisfactorily, but many sets under ideal conditions can function on a signal strength of from 1 to 3 microvolts per meter. To bring such a signal to an audible level, however, requires an amplification of many millions.

SELECTIVITY

Selectivity is the ability of a receiver to respond to one particular signal (frequency) and reject all others. The degree of selectivity varies with the type of receiver. A radiotelephone receiver tunes more sharply than a commercial broadcast receiver, and a CW communication receiver is more selective still. For a comparison of the three tuning curves, see figure 7-9.

Carrier waves from commercial broadcast stations contain sideband frequencies which extend 5 kc on either side of the carrier frequency. If a station is transmitting on 1140 kc, the complete carrier wave contains frequencies from 1135 and 1145. If a receiver tunes too sharply, some of the sideband frequencies are lost, with a corresponding sacrifice of fidelity. The commercial broadcast receiver tuning curve shown in figure 7-9 is optimum. The top is broad and flat and the sides are steep. Actually, most a-m broadcast receivers have tuning curves resembling the broken line, and many frequency components of voice and music contained in the signal are not reproduced by the set.

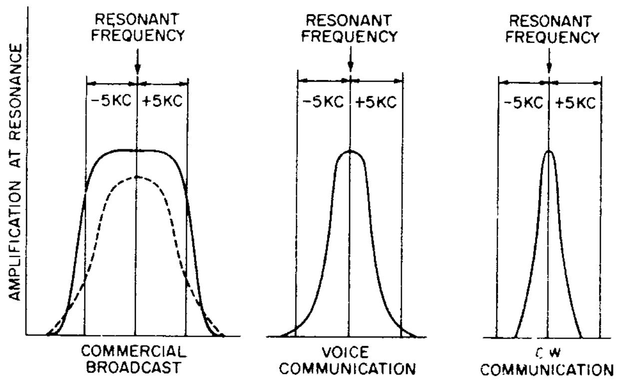

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Figure 7-9. —Comparison of receiver bandwidths.

Although sharp tuning in a home radio set would make for poor listening, it is desirable in military sets for the sake of frequency economy and reduction of interference. Radiotelephone messages can be sent on frequencies that extend only 2 kc on either side of the carrier frequency.

The CW sets tune so sharply that, unless an operator is careful, he can turn his dial through the signal without hearing it.

TYPES OF RECEIVERS

There are two major types of communication receivers: the tuned radiofrequency (TRF) and the superheterodyne.

Tuned Radiofrequency Receiver

In the TRF receiver, all frequency amplification takes place at the frequency of the incoming signal, and all tuned circuits must be adjusted to that frequency.

Without going into the technical aspects of the reasons, the TRF has several disadvantages. It is difficult to obtain uniform amplification of the r-f stages over the entire frequency range of the receiver. At the higher frequencies, the sensitivity of the receiver is reduced. The most serious drawback is that the selectivity of the tuned circuits cannot be kept uniform over the frequency range, selectivity decreasing at the high end of the frequency band.

Because of their inherent limitations, TRF receivers have largely been replaced. They are mentioned here only for familiarization purposes.

Superheterodyne Receiver

Most modern receivers are of the superheterodyne type. The main limitation of the TRF receiver is its inability to receive signals over a wide range of frequencies and at the same time to provide both high sensitivity and adequate selectivity. The ideal receiver would be one which had a different set of TRF circuits for each frequency to be received. The idea is for the most part impractical because such a set would be both expensive and bulky. But the reason such a receiver would be ideal is because each circuit could be set for maximum sensitivity and selectivity at the frequency it was designed to receive.

Once set, the resonant frequency of each tuned circuit would not be varied.

The superheterodyne receiver fills the gap between the TRF and what might be called a multiple TRF. All incoming signals are converted to one frequency, and at this frequency they are amplified before detection and audio amplification take place.

When a particular modulated radio wave is picked up by a superheterodyne receiver, it is sent through a stage called a mixer where it is changed to a new, preset frequency. The stages which then follow are tuned r-f amplifier stages, but they are tuned to one frequency only—the frequency to which all signals are converted by the mixer. The fact that these stages are always set to one frequency means that they can provide optimum sensitivity and selectivity regardless of the frequency of the carrier wave.

The frequency to which all signals are converted by the mixer is called the intermediate frequency (i-f). The i-f is considerably lower than the transmitted frequency, although still well above the audio range. The tuned r-f stages that amplify the i-f are referred to as i-f amplifiers.

An incoming r-f signal is combined in the mixer stage with another signal produced by a local oscillator. The i-f amplifier is tuned permanently to the frequency difference between the local oscillator and the incoming signal.

When the receiver tuning dial is set to receive on a particular frequency, the local oscillator is varied simultaneously. If the i-f stages are tuned to 500 kc, the oscillator is designed to oscillate at a frequency 500 kc above the incoming signal. Thus, if the tuning dial is set to receive a transmission of 1500 kc, the oscillator automatically adjusts to a frequency of 2000 kc. Actually, when the two frequencies are mixed, four frequencies result. The original frequencies remain and, in addition, the sum and difference frequencies are produced. When the two given signals (1500 and 2000 kc) beat against each other in the mixer, the four predominant signals are 1500, 2000, 3500, and 500 kc.

The i-f amplifiers, tuned to 500 kc, accept and amplify the difference frequency at the mixer output, and reject the other frequencies.

In cases where CW is received and Morse code signals are read directly by an operator, a beat-frequency oscillator produces a frequency differing from the i-f frequency by approximately 1000 cps. The differency frequency then is amplified to the audio range and fed to the operator's headset.

VOLUME CONTROL

Volume or gain controls are provided in receivers to permit changing the receiver sensitivity. These controls are necessary in order to compensate for differences in the strength of incoming signals.

Volume control can be manual or automatic. Automatic volume control (AVC)—sometimes called automatic gain control (AGC)—is used in all superheterodyne receivers and is desirable for several reasons. It prevents extreme variations in loudspeaker volume. When a receiver is tuned from a weak station (for which the volume has been turned up), to a strong station, the loudspeaker (or headset) will blast unpleasantly. The variations in signal strength due to fading also cause wide fluctuations in loudspeaker volume. Furthermore, variations in signal strength at the antenna, if not compensated for, can cause serious trouble by overloading the r-f, i-f, or detector stages of the receiver. Overloading causes distortion of the signal.

The AVC keeps the output volume at a constant level by reducing the amplification of certain stages in the receiver as the amplitude of a receiver signal increases. It affects weak as well as strong signals. When a receiver is tuned, the AVC usually is switched off to afford maximum amplification of weak signals. After tuning, the AVC is turned on, provided the signal is not too weak.

In some receivers a special type of AVC, called delayed automatic volume control (DAVC), is used. The DAVC-equipped receivers do not reduce amplification of a signal until a certain level is exceeded. In this way weak signals are not further weakened.

NOISE DISCRIMINATION

Highly sensitive superheterodyne receivers always have some background noise which appears in the output as hiss and crackles. Some noise arises in the receiver itself, while other noises are produced by lighting and manmade interference such as that caused by electric motors. Noise interference is bothersome at best, and at worst causes fragmentary reception. There are a number of devices designed to minimize the effects of interference.

The noise suppressor is similar to the tone control on a home receiver. When this control is tuned for bass reception, much of the noise is filtered out and is not permitted to reach the earphones. The noise suppressor, however, reduces the volume. On weak signals, it may be necessary to disconnect the suppressor from the circuit.

The output limiter is a safety device that prevents crashes of static from injuring the operator's eardrums. When the volume of sound reaches a certain level, the limiter is activated to prevent the sound from rising any higher.

Some receivers have silencer circuits that keep the set quiet when no signal is coming in. This is a convenience when standing by for a message, and it also eliminates the discomfort of standing a slack watch listening to static.

ANTENNAS

The function of a receiving antenna is to intercept a portion of the energy radiated from a distant transmitting antenna. The magnitude of the received signal depends mainly on the intensity of the radiated wave.

The function of a transmitting antenna is to convert the r-f energy generated by the transmitter into the form of an electromagnetic wave, so that the energy may be propagated to distant points on the earth. The strength of the magnetic field surrounding a wire is proportional to the amount of current flowing through it. It follows that the strength of the field radiated from an antenna is proportional to the amount of current flowing through the antenna. The amount of current, and consequently the intensity of radiation, is maximum when the antenna is resonant to the applied frequency.

The shortest wire (antenna) which is resonant to a particular frequency is one whose length is equal to one-half the wavelength at that frequency. The reason for this is demonstrated in figure 7-10.

Alternating current (a-c) travels in cycles. In the time that elapses during the first half-cycle of an applied wave, the electrons move from the transmitter to point Y where, having no further path to follow, they bunch up.

At the end of the first half-cycle, the current reverses. The electrons travel back to point X, where they again bunch up. Points X and Y are the points of maximum impedance. Impedance (symbol Z) is the total opposition (resistance (R) and reactance (X) to the flow of alternating current. The antenna in this case is just enough to permit an electric charge to travel from one end of the wire to the other end back again in the time of 1 cycle. The complete distance traveled by the charge is 1 wavelength. Because the charge travels in length of the wire twice, the length of wire needed to have a charge travel 1 complete wavelength in 1 cycle is one-half a wavelength. This length of wire, known as a half-wave antenna or dipole, is the shortest resonant length for a given frequency.

As the alternating current changes direction, there is an infinitely small interval when no current flows. The electromagnetic field at once begins to collapse; but, even though the energy is moving at the speed of light, the outermost part of the field cannot return to point X before the next one-half alternation throws up a new field of opposite polarity. The returning field then is pushed away from the antenna and becomes a free wave of electromagnetic energy radiating through space. The

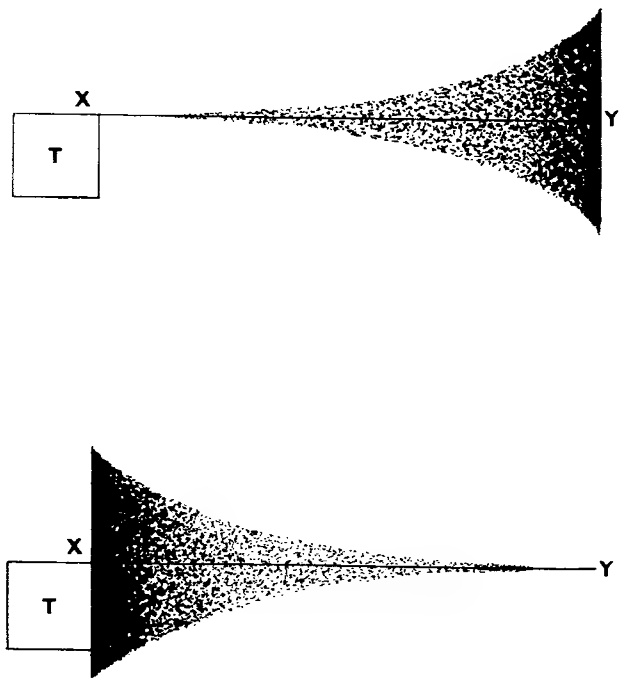

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Figure 7-10. —With a half-wave antenna, the electric charge travels the length of the wire twice. The complete distance covered by the charge is 1 wavelength.

returning field then is pushed away from the antenna and becomes a free wave of electromagnetic energy radiating through space. The principle of the half-wave antenna is the basis for all antenna theory.

If the frequency of a dipole is doubled, the length remaining unchanged, the antenna will be resonant to the double frequency because the electron flow keeps step with input energy. The antenna then is said to be operating at its second harmonic; it can be resonant at harmonics several times the fundamental frequency. A resonant condition also results if the length of the antenna is doubled, so that it becomes a full wavelength long.

The wavelength of a radiofrequency may vary from several miles to a fraction of an inch. We stated previously that a radio wavelength usually is measured in meters rather than in feet and inches. Because a radio wave travels at a constant speed of 186,000 miles (300,000,000 meters) per second, the length of 1 cycle, or 1 wavelength, is determined by dividing wave velocity by wave frequency. By conversion, the formula holds whether the frequency is given in cycles, kilocycles, or megacycles. In the following formulas, the figure 984 is derived from the fact that a meter is equal to 3.28 feet. Frequency is indicated by f, wavelength by W.

1. When frequency is expressed in cps:

$$\frac{300,000,000}{\text{f (in cps)}} = \text{W in meters}$$

or

$$\frac{984,000,000}{\text{f (in cps)}} = \text{W in feet}$$

2. When frequency is expressed in kc:

$$\frac{300,000}{\text{f (in kc)}} = \text{W in meters}$$

or

$$\frac{984,000}{\text{f (in kc)}} = \text{W in feet}$$

3. When frequency is expressed in mc:

$$\frac{300}{\text{f (in mc)}} = \text{W in meters}$$

or

$$\frac{984}{\text{f (in mc)}} = \text{W in feet}$$

The required physical length of the antenna in each example is one-half the wavelength.

STANDING WAVES

If an antenna is energized by an alternating current of a frequency equal to the antenna's frequency, the current and voltage values along the length of the wire, and are always 90° out of phase. In a dipole, current is maximum in the center and minimum at the ends. The points where voltage or current are maximum are called voltage or current loops. The points of minimum voltage or current are known as voltage or current nodes. Figure 7-11 shows the location of loop and node points along a full-wave antenna. Current and voltage nodes appear every one-half wavelength, but are separated by one-quarter wavelength.

The wave of energy sent out by the transmitter travels to the end of the antenna, from where it is reflected back along the length of the wire. The time required for this process depends upon the length of the antenna, and hence upon the frequency (see fig. 7-10).

If the dipole is resonant to the frequency generated by the transmitter, the returning wave strikes the fresh oncoming wave and the current and voltage in the two waves reinforce each other. This condition is constant as long as the antenna is energized, and the effect is the same as though there were standing waves along the length of the wire, as is really the case. Only in the presence of standing waves is an antenna radiating at maximum.

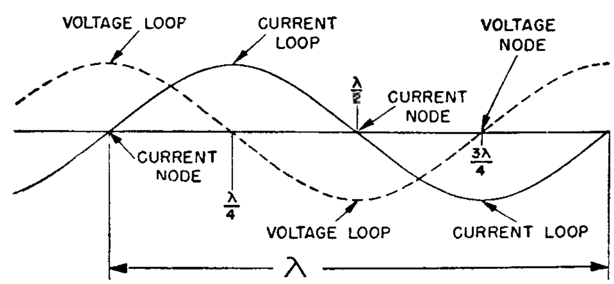

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Figure 7-11.—Standing waves along full-wave antenna.

PHYSICAL AND ELECTRICAL ANTENNA LENGTH

Although radiated r-f energy travels at the speed of light through free space, there is a difference in velocity between a radio wave traveling in space and a radio wave moving across an antenna. The difference is caused by the circumference of the wire (resistance to flow), the presence of insulators, and perhaps the proximity of nearby objects. An antenna never is completely isolated from its surroundings. The phenomenon of retardation is referred to as end effect, because the ends of the antenna, in effect, are made farther apart electrically than they are physically. Consequently, the physical length of a dipole should be about 5 percent shorter than the corresponding wavelength in free space.

Assume that a station is to transmit on a frequency of 3 mc. Applying the formula for finding wavelength, we find that:

$$\frac{300}{3} = 100 \text{ meters or, if you prefer,}$$

$$\frac{984}{3} = 328 \text{ feet.}$$

In the ideal situation, the physical length of an antenna for a transmitting frequency of 3 mc is therefore 164 feet (one-half wavelength). Because the ideal situation does not exist, the physical length is adjusted by 5 percent. The correct antenna length for a 3-mc transmission then becomes 156 feet.

HALF-WAVE DIPOLE

The half-wave dipole (sometimes called a Hertz antenna) has a length approximately equal to one-half a wavelength at the frequency being transmitted. It must be remembered that a transmitter is merely a high voltage generator of alternating current. If a feeder line from a transmitter is connected to the center of a dipole, the antenna will act as though an a-c generator were set between two quarter-wave antennas, as in figure 7-11. During one-half of the generator's alternation, electrons in the antenna will flow from right to left (fig. 7-12A). On the next half alternation, electrons flow in the opposite direction.

The dipole is the basis for many complex antennas. When employed for transmitting medium and high frequencies, usually it is constructed of wire. At very high and ultrahigh frequencies, the shorter wavelength permits construction utilizing metal rods or tubing. Depending upon the wave polarization desired, the dipole may be mounted either horizontally or vertically. Because it is an ungrounded antenna, the dipole may be installed far above the ground or absorbing structures.

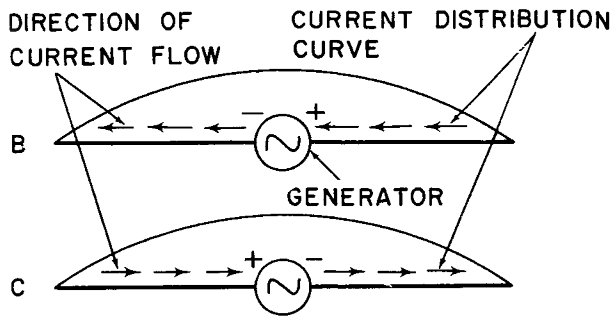

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Figure 7-12. —Instananeous direction and distribution of current in a dipole.

A dipole suspended in space, away from the influence of the earth, is surrounded by an electromagnetic field resembling the shape of a doughnut. Very little radiation takes place at the ends of the dipole. When the antenna is vertical, radiation emanates predominantly on a horizontal plane. Conversely, if the dipole is horizontal, radiation emanates in a vertical pattern, as of a doughnut standing on edge. Maximum radiation, then, takes place in a plane perpendicular to the axis of the antenna.

At low and medium frequencies, half-wave antennas are physically too long for practical use aboard ship and at many shore stations. Dipoles for 500-kc transmissions, for example, require a length of about 936 feet. At these lower frequencies, the quarter-wave antenna affords a solution to the problem of undue antenna length.

QUARTER-WAVE ANTENNA

The principle of the quarter-wave antenna (also known as the Marconi or grounded antenna) is illustrated in figure 7-13. The transmitter is connected electrically to the earth. Although the antenna is only a quarter-wavelength, the earth itself acts as another quarter-wave antenna. By the aid of this

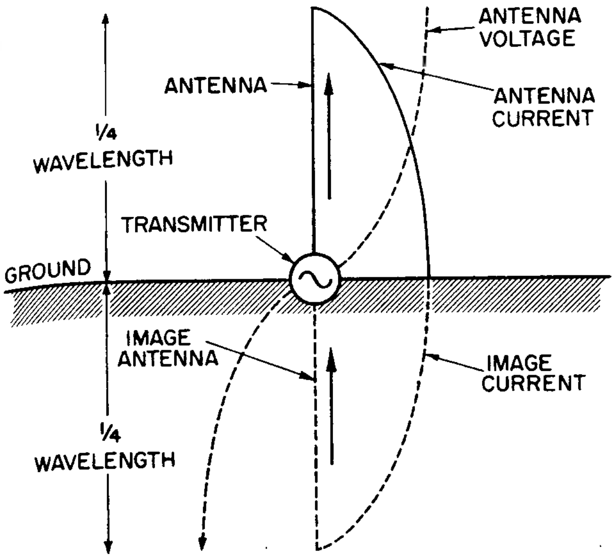

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Figure 7-13. —Vertically mounted quarter-wave antenna.

image wave in the earth, half-wave operation is obtained from an antenna half the size of a dipole.

The relationship of current and voltage in a quarter-wave antenna is similar to that in a dipole. Voltage is maximum at the top of the antenna and minimum at the bottom. Current is greatest at the bottom and least at the top.

The quarter-wave antenna is used extensively with portable transmitters. On the airplane, a quarter-wave mast or a trailing wire is the antenna, and the fuselage produces the image. Similar installations are made on ships. A quarter-wave mast or horizontal wire is the antenna, and the superstructure and hull provide the image.

TYPICAL SHIPBOARD ANTENNAS

Problems not usually present in land installations arise when antennas are installed on board ship. Most of the masts, stacks, and other structures above decks are grounded to the ship's hull and, through the hull, to the water. To obtain adequate coverage from the antenna, it must be installed so that minimum distortion of the radiation pattern results from grounded structures.

Wire Antenna

A wire antenna, installed on board ship for medium- and high-frequency coverage, consists of a wire rope strung either vertically or horizontally from the yardarm or the mast to outriggers, another mast, or to the superstructure. Usually the wire is made of phosphor-bronze, a material that resists corrosion and is nonmagnetic.

Wire receiving antennas normally are installed forward, rising nearly vertically from the pilothouse top to brackets on the mast or yardarm. They are located as far as possible from the transmitting antennas so that a minimum of energy is picked up from the local transmitters. The transmission line (lead-in) for each receiving antenna terminates in antenna transfer panels in the radio spaces.

The transmitting antenna transmission lines may be coaxial cable or metal tubing supported on standoff insulators and enclosed in rectangular metal ducts called antenna trunks. Each transmission line connects with an individual transmitter or with an antenna multicoupler which permits the use of an antenna with more than one transmitter.

The metal rings, outside antenna transfer switches, antenna hardware, and accessories associated with transmitting antennas are painted red. Hardware and accessories used with receiving antennas are painted blue. This color scheme is a safety precaution that indicates, at a glance, whether an antenna is used for receiving or transmitting.

Whip Antenna

Whip-type antennas are essentially self-supporting and may be installed in many locations aboard ship. They may be deck-mounted or mounted on brackets on the stacks or superstructure.

Whip antennas commonly used aboard ship are 25, 28, or 35 feet in length and are made up of several sections.

On aircraft carriers, whip antennas located along the edges of the flight deck can be tilted. The tilting whip is pivoted on a trunnion and is equipped with a handle for raising and lowering the antenna. A counterweight at the base, of the antenna is heavy enough to nearly balance the antenna in any position.

Several special types of tilting mounts for whip antennas are used aboard submarines.

They are called erecting mechanisms, and in many cases may be operated from within the submarine. In most installations, as the submarine dives, the force of the water causes the whip to be folded back from a vertical to a horizontal position. A catch holds the antenna in this position. When the submarine surfaces, the catch is released and a spring mechanism causes the antenna to snap back to its vertical position. In the newer submarines, the whip antennas are mounted on retractable masts so that the antenna may be raised or lowered from within the submarine in much the same manner as the periscope.

VHF-UHF Antennas

The relatively short wavelengths at very high and ultrahigh frequencies enable the use of relatively small antennas. Vertically polarized, usually either dipole or quarter-wave, antennas are employed for all shipbaord external VHF-UHF communications. The antennas are installed as high and as much in the clear as possible to exclude as much as possible unwanted directivity in the radiation pattern caused by nearby masts, rigging, and cables.

Antenna Tuning

Previously we discussed the physical versus the electrical length of an antenna and postulated formulas to compute the required physical length of the antenna for a given frequency. Shipboard antennas usually are not of the proper length to give optimum performance at each desired operating frequency. There are several reasons for this condition. Many antennas are of a standard size and shape; available space may determine the type of antenna installed; antennas are designed to be operated at a number of frequencies.

It is physically and operationally impossible to lengthen or shorten an antenna each time the transmitter is changed to a new frequency. All transmitters, however, must be able to operate at any frequency within its tuning range. It is therefore necessary to employ some means for adjusting the antenna for reasonable efficiency at any frequency, regardless of the physical size or arrangement of the antenna.

Because each transmitter usually is associated with only one antenna of fixed length, adjustment of the effective length may be made electrically. This process, called antenna tuning, is accomplished by electronically adding either inductance or capacitance to the antenna at the point where it is fed from the transmitter or transmission line. Added inductance has the effect of increasing the electrical length of the antenna; capacitance decreases the length. In this manner the antenna is made to respond as though it has a number of quarter waves along its length. By tuning the antenna properly, the standing waves are increased and the radiated energy is increased.

Emergency Antennas

Loss or damage to an antenna, and consequent disruption of communications, may result from heavy seas, violent winds, or enemy action. It is not unusual for sections of a whip antenna to be carried away or insulators to be damaged. Emergency antennas, cut to proper lengths and with necessary insulators and other hardware installed, should be available and readily accessible in the ship's radio spaces.

The design of emergency antennas may be influenced by the type of ship, the location of transmitting receiving equipments, availability of space, and the suitability of structures for rigging the antenna quickly.

The simplest emergency antenna consists of the proper length of wire rope to one end of which is attached a high-voltage insulator and to the other end of which is soldered a heavy alligator clip or lug. To rig the antenna, the insulator end of the rope is hoisted to the nearest mast, the yardarm, or other high structure and secured. The opposite end of the rope is attached to the equipment transmission line by means of the clip or lug. To radiate effectively, the antenna must be sufficiently clear of all grounded objects.

TYPICAL SHORE STATION ANTENNAS

Unless physical dimensions are the fundamental consideration, a given type of antenna may be utilized practically anywhere. The rhombic, sleeve, and conical antennas described herein are considered mainly as shore station antennas. With technological advances, however, the sleeve and conical antennas have been modified for shipboard use and are employed both ashore and afloat. The three antennas discussed are only a sampling of many.

Rhombic

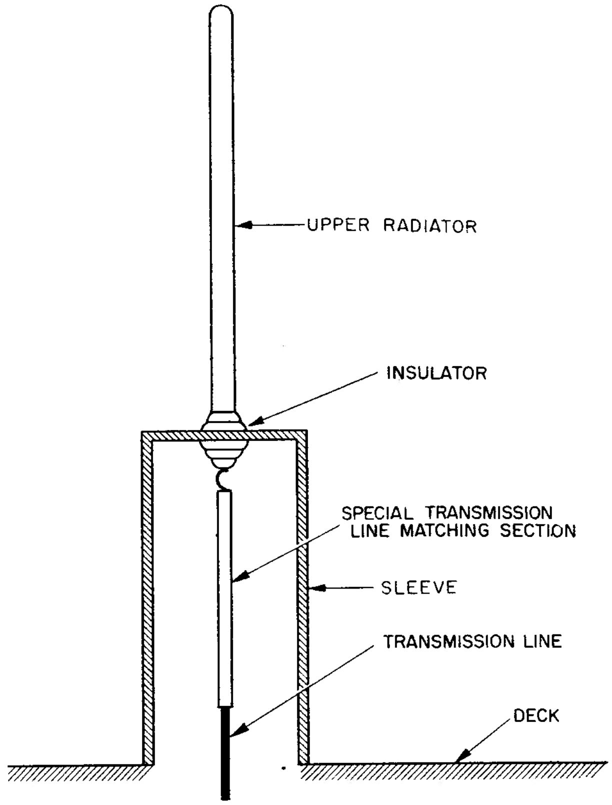
The rhombic antenna is extremely useful for long-range, point-to-point communications. As shown in figure 7-14, the characteristic radiation pattern is such that most of the r-f energy is released at the point of the antenna farthest from, and in a direction away from, the transmission line from the transmitter. The pattern is highly directive. Although permanently installed, the rhombic may be "pointed" toward the intended receiving station.

The basic rhombic has four straight wires joined to form the diamond, and it is suspended horizontally from four poles. Each leg of the antenna is at least 1 or 2 wavelengths at the operating frequency. The length may be as many as 12 or more wavelengths, so that rhombics, even for high-frequency operations, have leg lengths of several hundred feet.

The performance of the rhombic antenna is improved when more than a single wire is used to form the legs. The most common multiwire rhombic is the three-wire type, which provides an improved match to the transmission line and, when used for receiving, greatly reduces the noise caused by precipitation static. The three-wire rhombic antenna is the only rhombic installed at both transmitting and receiving station.

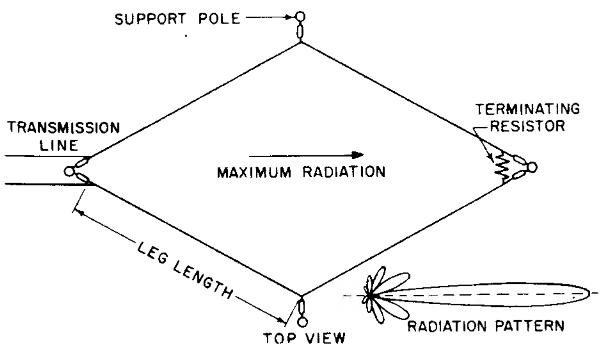
Sleeve

The sleeve antenna (figure 7-15 shows the shipboard version) is especially helpful in reducing the number of conventional narrow-band antennas that otherwise would be needed to meet the requirements of shore stations. Through the use of multicouplers, one sleeve antenna can serve several transmitters operating over a wide range of frequencies. This reduces the number of antennas without sacrificing required communication channels. The broad-band feature makes the sleeve desirable for use in small antenna sites.



25.217

Figure 7-15.—Shipboard sleeve antenna.



13.37

Figure 7-14.—Typical rhombic antenna.

Conical

The conical, or conical monopole, antenna is a broad-band antenna used extensively both ashore and aboard ship. It utilizes two methods of radiation.

When operating at frequencies near the lower limit of the HF band, the conical radiates in much the same manner as a regular vertical antenna. At higher frequencies only the lower cone section radiates, and the top section has the effect of exerting pressure on the lower section, pushing the signal out at a low angle. The low angle of radiation causes the skywave to return to earth at great distances from the

antenna. The conical monopole antenna, therefore, is well suited for long-distance communication in the high-frequency range.

FACSIMILE

The general uses of FAX were discussed in chapter 4. In this section we cover briefly the principles of operation of facsimile equipment.

The most useful application of facsimile has proved to be the transmitting of fully plotted weather charts, which has eliminated the need for skilled weather analysts and duplicate plotting aboard each ship and station where weather information is required. Significant economics, as well as a more uniform, accurate, and rapid weather service have been effected.

The Navy has a number of facsimile equipments in use. All operate in much the same way. The picture to be sent is wrapped around a cylinder on the transmitting machine. It is necessary that the picture lie perfectly flat, for variations in the surface planes cause faulty transmission of the intelligence. The cylinder rotates at a constant speed and at the same time moves longitudinally along a shaft. The picture is illuminated by a beam of light focused through a condensing lens. As the beam passes over each portion of the picture, it is reflected into a photoelectric tube, and the variation in intensity of reflected light due to the character of the picture creates voltage variations in the tube output circuit. These voltage variations constitute the picture signal and may be sent directly over a landline or used to modulate the radiofrequency carrier of a transmitter.

The photoelectric tube has been called the electric eye, but it does not have the capacity of the eye or camera lens to view many images simultaneously. It can only measure the light value of any single area toward which it is directed. It is not possible with present equipment to show the picture to the tube for an instant and expect it to analyze the intelligence for transmission. Rather, it is necessary to divide the picture into small areas containing monotone values of detail, which the photoelectric tube is capable of analyzing correctly. Thus, facsimile uses a scanning principle, and allows the photoelectric tube to view a spiraling area one one-hundredths inch wide. As the drum rotates and moves longitudinally, consecutive areas are viewed by the tube until the entire picture has been analyzed for transmission.

At the receiver the signal is demodulated and the voltage variations are used to operate a recorder in synchronization with the transmitter. If the transmission is to be recorded on photographic film or paper, the signal reaching the receiver is amplified until it is strong enough to operate a neon recorder lamp. The lamp scans sensitized paper or film on the drum, reception taking place in a darkroom. The paper or film is exposed in varying degrees corresponding to the image viewed by the photoelectric tube in the transmitter. In the case of film, photographic development yields a negative which may be used for making prints.

Where it is desirable to operate without a darkroom or chemicals, the nonphotographic process is preferable. One type of FAX receiver employs a device called a bar, hammer, or helix, which produces a picture by pressing down on carbon paper with pressures varying according to the transmitted picture. A second and more common type records on a specially prepared paper by what is literally a burning process. A stylus is connected to the output of the recorder amplifier in such a way that a high voltage is developed at the stylus point as signals are received. The electrified stylus burns a white surface coating on the paper which has a conductive black undercoating. One type of this paper may be used for making copies by the gelatin-ink transfer (hectograph) process.

One of the greatest problems in the development of facsimile, and still a difficulty of operation and maintenance, is synchronizing the transmitting and receiving drums. As the scanning begins, both drums must be revolving at exactly the same speed. This is accomplished by a sealed, temperature-compensated, tuned fork which vibrates at 1800 cycles per second. A frequency variation of as little as one-tenth cycle will, in 20 minutes, cause an inch of skew in the received copy.

A difficulty encountered in any transmission circuit, especially over long distances, is interference. In CW, voice, or RATT, bursts of noise obliterate a portion of the signal and repeats may be required. In facsimile, bursts of interference cause a one one-hundredth inch line through a portion of the picture, but leave it readable. A number of systems for minimizing fading and interference are in use. At present the Navy is concentrating on frequency-shift keying for facsimile transmissions.

TELETYPEWRITERS

Shore station RATT procedures are discussed in chapter 4. Large ships having the equipment and capability may be designated as tributaries in the Navy Teletypewriter and Tape Relay Network. Such ships include specially equipped communication ships and mobile fleet and task force command ships.

Most other ships, although not a part of the NTX, are equipped with radioteletypewriters for ship-ship and ship-shore communications. Generally, units not included in the NTX but having these equipments utilize what is referred to as manual teletypewriter procedure. In practice, manual teletype and NTX procedures are identical in many respects.

In most cases, for example, an operator may transmit either manually or by means of a tape. The former is useful for communicating between relatively nearby ships in the same force. A tape might be more practicable for lengthy messages that must be relayed or when the flagship has NTX relay capabilities.

When two teletypewriters are not joined by wire, the gap between the machines must be bridged by radio. To bridge the gap, a radio transmitter and receiver are needed. Two modes of operation are used: tone modulated and frequency shift keying (FSK). Tone modulating RATT generally is employed for close-range operations. A transmitter produces the r-f carrier wave to convey the intelligence. A device known as a keyer changes direct-current electrical pulses from the teletypewriter into mark and space modulation. A tone terminal changes the signals to audio tones. The transmitter impresses the audio tones on the carrier wave.

At the receiving station, a radio receiver and a converter change the r-f signals back to d-c pulses. The modulated carrier wave enters the receiver, which extracts the signal intelligence and sends the audio tones to the tone converter. The converter changes the audio tones into d-c mark and space signals for the page printer.

Frequency shift keying is a mode of operation usually employed in long-range communications. The r-f signal is shifted a small amount (425 cycles) above the carrier and the same amount below the carrier to produce mark and space signals, respectively, to correspond to the mark-space teletypewriter code.

All teletypewriter signals pass through the shipboard teletypewriter panel, which provides every possible RATT interconnection available on board. This operational flexibility provides maximum efficiency with the fewest number of circuits and the least amount of equipment.

Due to the volume of classified information that is transmitted in message form, and the inherent need for expeditious traffic handling, the use of on-line communications is increasing in importance.

By means of the on-line process, all information, regardless of classification, is simultaneously encrypted, transmitted, received, and decrypted in one operation. This procedure is especially beneficial for fleet broadcasts and point-to-point communications. Automatic crypto devices and associated teletypewriter equipments always are employed. When two stations cannot be linked by cable or landline, transmitting and receiving equipments also must be utilized.

On-line operations eliminate manual encryption/decryption procedures, speed up traffic handling, and provide positive security against traffic analysis. On the other hand, the system is sophisticated and complex, requiring skilled repairmen and trained operating personnel.

In the off-line method, messages are encrypted manually, relayed by any means, and decrypted manually in separate steps. Off-line operations are being phased out gradually.